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FEDERAL COMMUNICATIONS COMMISSION
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Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the matter of Allocation of Spectrum in the 5 GHz Band To establish a Wireless Component of the National Information Infrastructure	RE: RM-8653

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To: The Acting Secretary

Comments on
Apple Computer's Petition for Rulemaking "NII Band" dtd May 24, 1995

July 10, 1995

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Summary of Comments

Pulson Communications ("Pulson") has developed an ultra-wideband ("UWB") radio technology. Pulson's UWB signal's have RF bandwidths approximately equal to the signal's center frequency, e.g., our 650 MHz UWB radio has half power bandwidth of approximately 650 MHz and our 2 GHz UWB radio has a half power bandwidth of approximately 2 GHz

Pulson Communications wholeheartedly supports efforts to refarm the electromagnetic spectrum to allow for its more effective utilization; however, Pulson wishes the FCC to note that research done by Pulson and others shows

1) For "bursty" traffic (i.e., non-broadcast traffic), it is inefficient to partition spectrum into narrow bands. Rather, to maximize the capacity of electromagnetic spectrum one must use signals with the widest possible RF bandwidth, e.g., ultra-wideband techniques

2) The ability of disparate systems to share spectrum is improved when those systems appear to be white noise/Gaussian white noise to each other and transmitted power levels are minimized.

3) In cluttered RF environments (which includes in-building, urban and suburban areas), UWB techniques are again preferable to narrowband techniques [1] because of their superior ability to resolve multipath, thereby eliminating Rayleigh fading, the consequence of which is that transmit power levels can be reduced by 20 dB or more.

Pulson Communications also wishes the FCC to note that while Apple Computer claims the implementation of its request would advance U.S. technology, the wireless technology Apple cited throughout its document was Europe's HIPERLAN standard.

As a result of its research and its understanding of the research of others, Pulson advises the FCC to:

1) Reject Apple's specific proposal.

2) Refrain from issuing and renewing any narrowband licenses in the frequency band from 2.5 GHz to 8.5 GHz thereby clearing the band over a period of many years. Alternatively, a 2 GHz band centered around 5.5 GHz should be cleared.

3) Adopt rules allowing only the use of UWB technologies with a center frequency of 5.5 GHz and bandwidths in excess of 4 GHz; such rules to be consistent with

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[1] Relative of Pulson's UWB technology, narrowband techniques include traditional narrowband and spread spectrum techniques.

spectrum sharing. If only 2 GHz of bandwidth can be cleared then 2 GHz bandwidth-limited UWB systems with a center frequency of 5.5 GHz should be allowed.

4) Reduce constraints over time on the UWB systems in this band as narrow band systems go out of service.

Pulson believes this path, and not Apple's, will lead to (1) maximizing the capacity of the spectrum; (2) the most practical high information bandwidth nomadic wireless systems; and (3) the advancement the U.S. communications technology base.

Pulson Communications

Pulson Communications is a small, privately held company funding the development of ultra-wideband impulse radio. The FCC has been briefed numerous times by Pulson and other governmental agencies about Pulson's technology.

Pulson's technology is being developed by an engineering team in Huntsville, AL. [2]

This technology is covered by five U.S. patents [3] and many patents issued in other countries. We recently filed more patent applications.

Ultra-Wideband Technology

Pulson's UWB technology is described in two published papers:

1) Fullerton, L. W. and Withington, P., "An Impulse Radio Communications System", in Bertoni, H. L., Carin, L., & Felsen, L. B., *Ultra-Wideband Short Pulse Electromagnetics*, Plenum Press, 1993.
2) Scholtz, R. A., "Multiple Access with Time Hopping Impulse Modulation" (Invited Paper), IEEE MILCOM'93, Bedford, MA, Oct. 11 - 14, 1993.[4]

There are many techniques for generating and receiving UWB signals, some of which are described in open literature, e.g., reference (1) above. Pulson believes its technology is superior to all other UWB implementations for communications and radar.

From the FCC's perspective, the three key advantages of Pulson's UWB technology are:

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[2] Pulson holds a worldwide license to the technology for commercial communications applications from Time Domain Systems, Inc. ("TDSI"). TDSI retained rights to military applications.

[3] U.S. Patents: 4,641,317; 4,743,908; 4,813,057; 4.979,186; and 5,363,108.

[4] Prof. Scholtz is a co-author, along with Simon, Levitt and Omura, of *Spread Spectrum Communications*, McGraw-Hill, 2nd edition, 1994.

1) It is the most efficient technique for allocating spectrum for the sort of "bursty" traffic implied by Apple's request. Thus, the FCC can reduce spectrum congestion by shifting to UWB technology from narrowband technology.

2) It allows the resolution of multipath signals with sub-nanosecond delay differences and eliminates Rayleigh fading; consequently, there is no need to transmit extra power to overcome such fading (i.e., a fading margin). In a cluttered propagation environment, Pulson's system has superior performance to any other technology with equal bit rate, BER, and EIRP.

3) Pulson's Gaussian white noise signal has a naturally low power spectral density because of its great bandwidth and because there is no need to design in a Rayleigh fading power margin. The impulse signals used in Pulson's systems cause minimal impact to in-band narrowband systems as the intercepted power from its UWB signals is generally minuscule.

Inadequacy of Narrowband Techniques

Some additional data and analysis also helps explain why impulse radio has superior performance to narrowband systems.

Efficient Use of the Spectrum

There has been much discussion of the advantages of wideband systems in terms of maximizing the carrying capacity of spectrum. Basically, it is commonly recognized that spread spectrum signals improve the carrying capacity of spectrum for bursty traffic. This has been one of the main selling points of Qualcomm's cellular CDMA technology. Dr. Marvin Simon in a paper for Pulson showed that this fact is derived from the information theory and that UWB signals, being the widest bandwidth signals, are better at this than narrowband signals like spread spectrum.

Multipath

J. Shapira, when discussing the characteristics of his company's CDMA cellular technology, noted that "[t]he bandwidth required to match the in-building [propagation] channel, to resolve the multipath and to eliminate the fades, extends beyond 50 MHz." [5] Figure 1 shows the output of a digital sampling oscilloscope receiving a 2.5 GHz center frequency impulse after it has propagated through 5 meters within a multi-story office complex (and two walls with metal studs).

[5] Shapira, J., Qualcomm, Inc., "Channel Characteristics for Land Cellular Radio, and Their Systems Implications", *IEEE Antennas and Propagation Magazine*, Vol. 34, No. 4, August, 1992, p. 14.

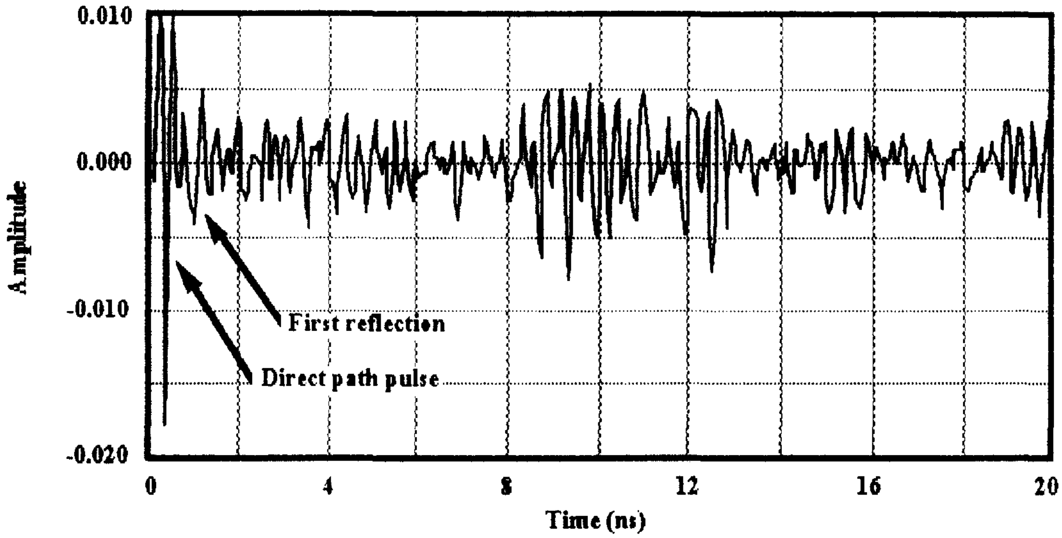

Figure 1. Propagation of a 2.5 GHz /c impulse. The propagated pulse, which resembles a "M", occurs in the first 0.5 ns.

Integrating over a large number of pulses, the digital sampling oscilloscope shows the direct path pulse and many multipath pulses, one of which occurred less than one nanosecond after the direct path pulse. Resolving these signals requires at least 2 GHz of bandwidth (a reflection occurring 0.5 ns after the direct path signal requires 1/0.5 ns = 2 GHz of bandwidth).

Figure 2 shows the signal in the frequency domain. Multipath in the frequency domain appears as nulls and peaks across the spectrum. Moving the receiving antenna would move the location of the fades, but not the total received power.

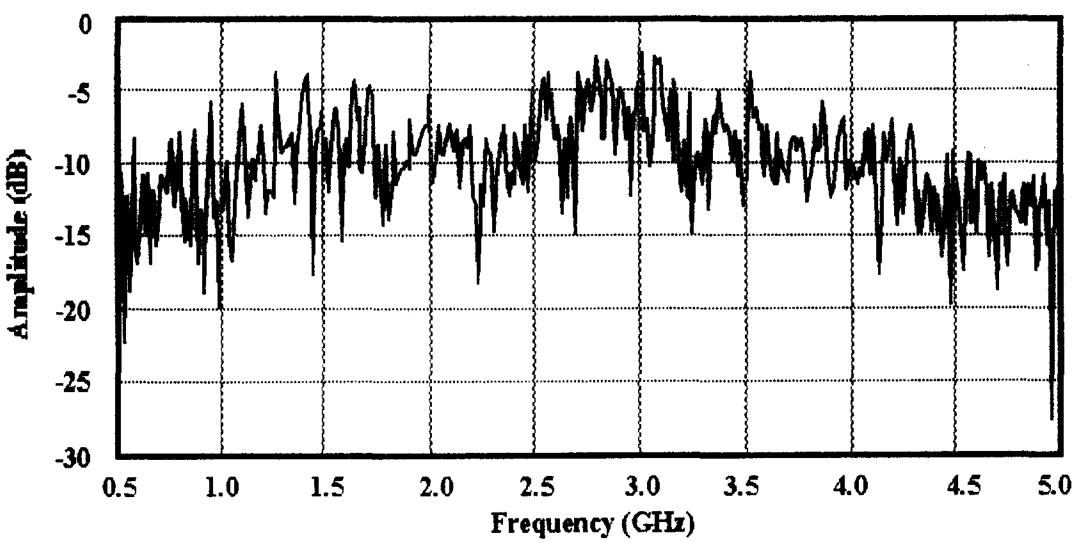

Figure 2. Received spectrum of 2.5 GHz impulse showing numerous fades greater than 10 dB.

Literature suggests that significantly deeper fades than shown in Figure 2 are common and that an ability to increase transmit power by 20 dB or more is required to provide a reliable communications link in a cluttered environment.[6]

Transmitted Power Vs Range in a Cluttered Environment

Some additional analysis illustrates the difficulties encountered with narrowband techniques in cluttered environments.

Consider the implications of a simple propagation model[7] for a 5.3 GHz signal transmitting 24 Mbps with a SNR of 15 dB[8]. Figure 3 shows the input power into an antenna with a gain of 3 dB to be received at a given distance by an ideal receiver also with a 3 dB gain antenna. Figure 3 depicts free space propagation (a $1/R^2$ propagation environment) and also cluttered propagation environments modeled as $1/R^3$ and $1/R^4$.

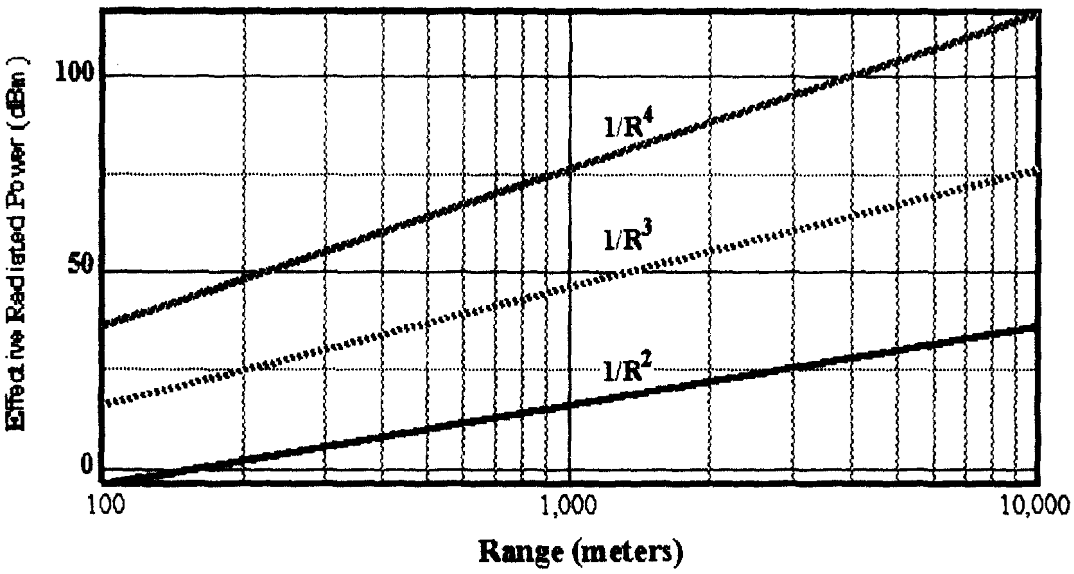

Figure 3. Power Vs Range – Power required to transmit 24 Mbps with a 15 dB SNR – No Fading Margin

These latter two propagation environments are about what is found in an in-building and cluttered urban environment.[9, 10]

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[6] See for example: Molkdar, D., "Review on radio propagation into and within buildings," *IEE Proceedings-H*, Vol. 138, No. 1, February, 1991, pps. 61 – 73.

[7] See enclosure for a summary of this model.

[8] A 15 dB SNR is sufficient to provide a bit error rate to needed for data communications applications, e.g., BER $\geq 10^{-10}$.

[9] Ibid.

[10] Seidel, S. Y. and Rappoport, T. S., "914 MHz Path Loss Prediction Models for Indoor Wireless Communications in Multifloor Buildings," *IEEE Transactions on Antennas and Propagation*, Vol. 40, No. 2, February, 1992, pps. 207 – 217.

The model estimates that in free space one would need -4 dB_m to go 100 meters; in a $1/R^3$ environment, 16 dB_m; and in a $1/R^4$ environment 36 dB_m (4 watts)

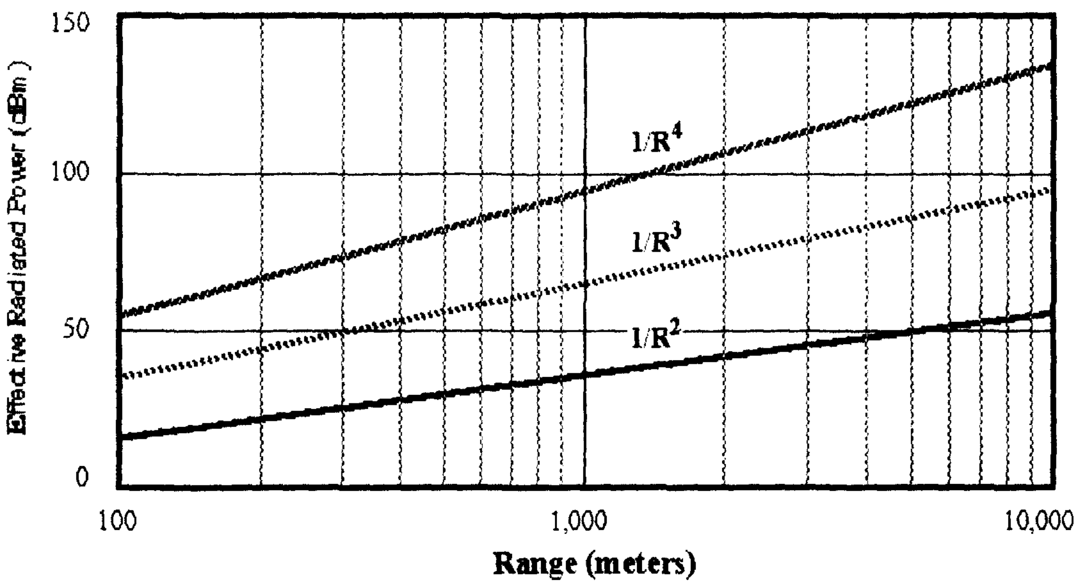


Figure 4. Power Vs Range – Assuming 20 dB Fading Margin

Figure 4 shows the results assuming a 20 dB fading margin – as would be required in an in-building environment to ensure a reasonably reliable link. In a $1/R^4$ environment one would need 56 dB_m (400 watts EIRP) for a reasonable quality signal.

Even at shorter ranges, significant power is required. Assuming a 20 dB fade margin and a $1/R^4$ environment, the predicted transmit power requirement is around 36 dB_m (4 watts EIRP) to go 30 meters.

These are fairly hefty signals for such short range communications. They also suggest that battery power consumption would be excessive for nomadic applications and that they might cause EMI as is now being experienced with cellular phones.

This model may not be precise, but given Apple's concept of a wireless high speed local area network running at 24 Mbps or higher, it is good enough to predict that:

- A narrowband system would require excessively large transmit power levels.
- A technology that eliminated Rayleigh fades would significantly reduce the transmit power requirement.

Moreover, notebook computer users are already dissatisfied with battery life; adding a RF transmitter that draws multiple of watts of power will not add to their satisfaction.

Strength of UWB Technology

An impulse signal would need the same power indicated in Figure 3 for equivalent performance, e.g., an ideal impulse transmitter would have to emit a 4 W signal in a $1/R^4$ environment to go 100 meters. But it would not require 400 watts to overcome moderate fades because there aren't any fades.

Additionally, when Pulson's Gaussian monocycle impulse signal is centered at 5.5 GHz it would have energy from below 3 GHz to above 8 GHz and its power spectral density ("PSD") would be relatively low. For example, a 4 watt signal would have white noise signal power of approximately 0.6 mW over the range 5.5 GHz ± 0.5 MHz. For a 5.5 GHz Gaussian monocycle, the peak power is at 5.5 GHz; at all other frequencies the PSD is lower. With 40 mW the white noise power over that same 1 MHz range would be 0.006 mW.

At these power levels, a UWB system minimizes interference potential and would have significantly better battery performance than any narrowband system.

Conclusions

Information theory shows that UWB techniques will yield the most capacity from the electromagnetic spectrum.

Traditional and well tested propagation models show that narrowband techniques lead to undesirable results for the sorts of applications suggested by Apple. However, UWB techniques do not suffer from those debilitating qualities.

The FCC should deny Apple's specific request and take a different path. That path should be to clear away spectrum for UWB systems. Given that the band between 2.5 and 8.5 GHz is inefficiently utilized and in some cases past users have stopped using the band altogether (and moreover, has reasonably good propagation characteristics for nomadic applications), it would be best to stop issuing and renewing licenses for this band. Thus, after many years, narrowband users would cease to use this band.

The FCC should establish rules for the use of UWB systems on the 2.5 GHz to 8.5 GHz band (the approximate half-power bandwidth of a 5.5 GHz center frequency Gaussian monocycle), so that users can benefit from its superior performance. Over time, as obsolete narrowband users clear the band, regulations required specifically for spectrum sharing between narrowband and UWB systems can be relaxed and finally eliminated on UWB systems.

Alternatively, if the FCC finds clearing such a large band impossible, it should authorize the use of UWB systems with their bandwidths constrained to 2 GHz. This would retain, in large part, the strengths the UWB technology and lessen the effort to clear spectrum.[11]

[11] See Pulson Communication's pioneer preference filing for additional information on bandwidth limited UWB signals.

Simple Propagation Model
Enclosure

This program estimates the achievable number of channels vs. range for a given set of parameters. The parameters are: center frequency (f_c), SNR, antenna gains (G_r & G_t), the propagation exponential factor (s; where s=2 for free space), requisite margin (A_{margin}), and transmitter output power ($P_{\mu W}$). Range (r) is in meters. Bit rate (B_r) is in kilobits per second.

$f_c = 5.3$ GHz $\quad G_r = 3$ dBi $\quad G_t = 3$ dBi $\quad k = 1.38 \cdot 10^{-23}$ $\quad T = 300$

$SNR \equiv 15$ dB

$A_{margin} := 20$ dB (Rayleigh fading margin)

Channel_Rate := 24000 (in kbps)

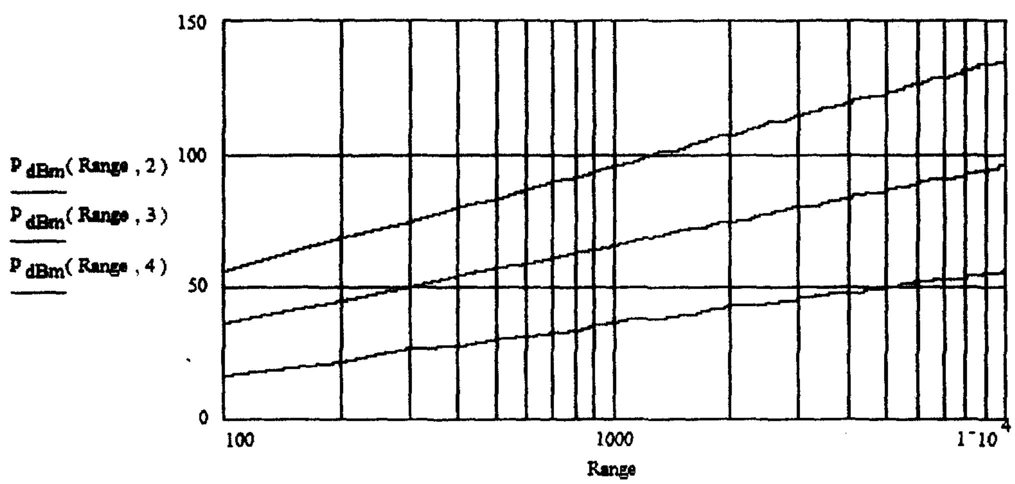
Gains, losses and SNR requirement:

$$X := 10 \cdot \log(k \cdot T) + 20 \cdot \log(f_c) + 62.45 - G_r - G_t + SNR$$

Transmit Power Function:

$$P_{dBm}(r, s) := 10 \cdot \log(\text{Channel\_Rate}) + 10 \cdot s \cdot \log(r) + X + A_{margin} + 30$$

Graph results: Range := 100, 200 .. 10000 meters



Power required at a specific range: R := 30

$P_{dBm}(R, 2) = 5.45$ $\qquad P_{dBm}(R, 3) = 20.221$ $\qquad P_{dBm}(R, 4) = 34.992$